RIVAS Training Workshop 23/05/2013, Die Schmiede, Berlin, Germany
"Reducing railway induced ground vibration by interventions on the transmission path"

Railway induced ground vibration

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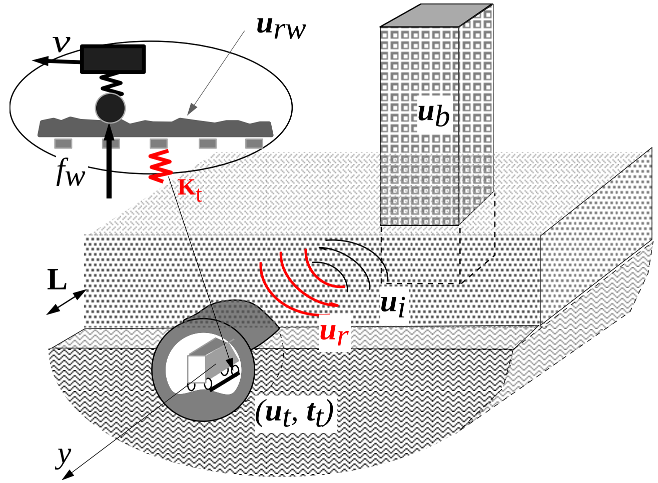
Outline

Outline of presentation

- Excitation mechanisms for ground-borne noise and vibration due to railway traffic.
- Studies on mitigation measures the transmission path within the frame of RIVAS.

Excitation mechanisms

Transmission path (ISO 14837-1:2005)



1. Loads applied by the vehicle on the track.
2. Dynamic track-soil interaction.
3. Transmission of vibrations through the soil.
4. Dynamic soil-structure interaction.
5. Vibration (1-80 Hz) and re-radiated noise (16-250 Hz) in the building.

Excitation mechanisms

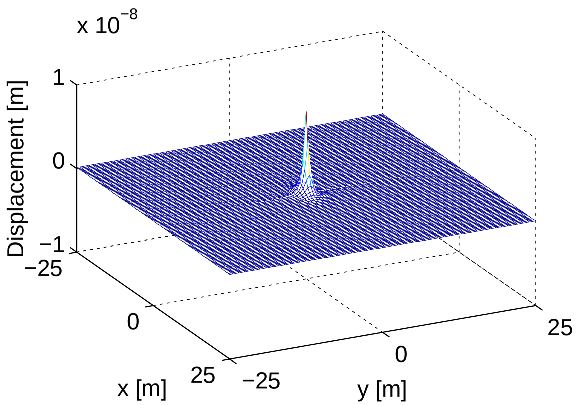
Quasi-static and dynamic excitation

- The loads applied by the train on the track can be decomposed into:
  – moving loads with constant amplitude: quasi-static excitation;
  – moving loads with time-varying amplitude: dynamic excitation.
- The response of the track and the soil to the moving load will depend on how the load speed relates to the wave velocities in the coupled system.
- For sufficiently small strain levels, the soil can be modelled as a layered elastic halfspace.
- At the free surface of an elastic halfspace, surface or Rayleigh waves develop that dominate the soil's response close to the surface.

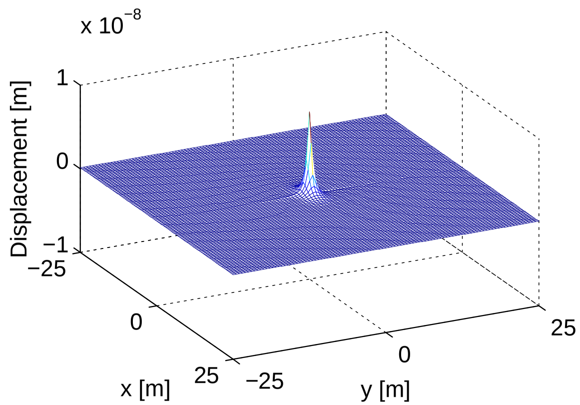
Excitation mechanisms

Quasi-static excitation: moving loads with constant amplitude

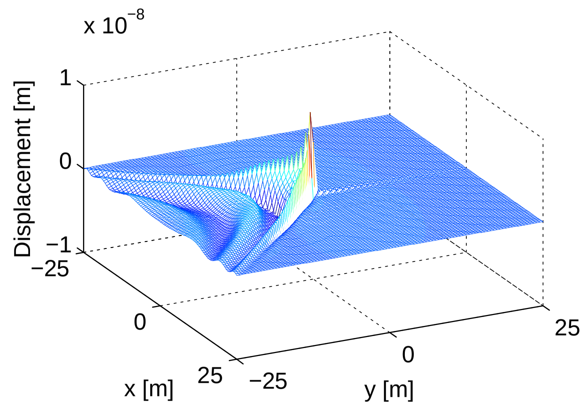
- Vertical response of a layered elastic halfspace for a load of constant amplitude travelling at different load speeds v.



$v = 0$



$v < \min C_{\mathrm{R}}$



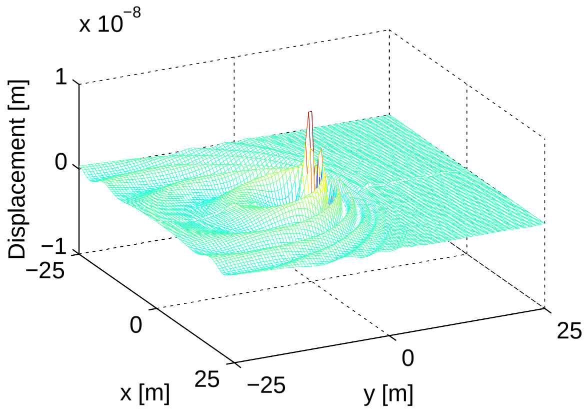
$v > \min C_{\mathrm{R}}$

- Trans-Rayleigh speeds only in case of high speed trains ($v \geq 180\,\mathrm{km/h}$) travelling on tracks supported by very soft soil ($C_{\mathrm{s}} \leq 50\,\mathrm{m/s}$).

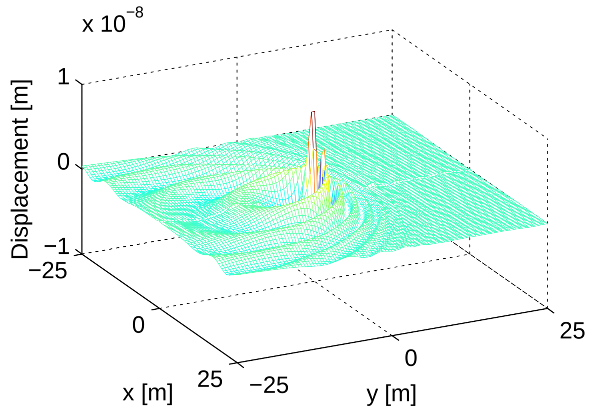
Excitation mechanisms

Dynamic excitation: moving loads with harmonic time variation

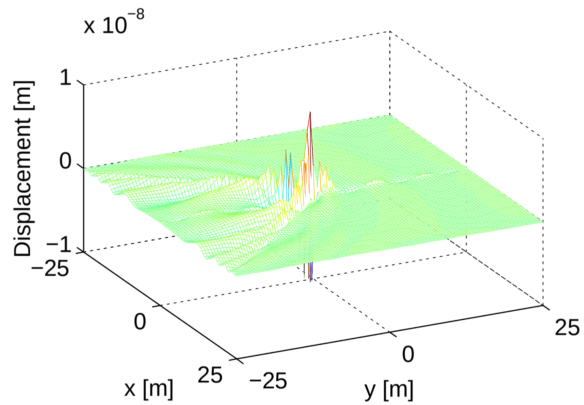
- Vertical response of a layered elastic halfspace for a load of harmonic amplitude travelling at different load speeds v.



$v = 0$



$v < \min C_{\mathrm{R}}$



$v > \min C_{\mathrm{R}}$

- A moving harmonic load generates propagating surface waves regardless of the load speed.

Excitation mechanisms

Mechanisms of dynamic excitation (ISO 14837-1.2-2004)

- Dynamic axle loads are due to vehicle-track interaction caused by:
  - Geometric wheel and track unevenness.
  - Impact excitation due to rail joints and wheel flats.
  - Parametric excitation due to spatial variation of support stiffness.

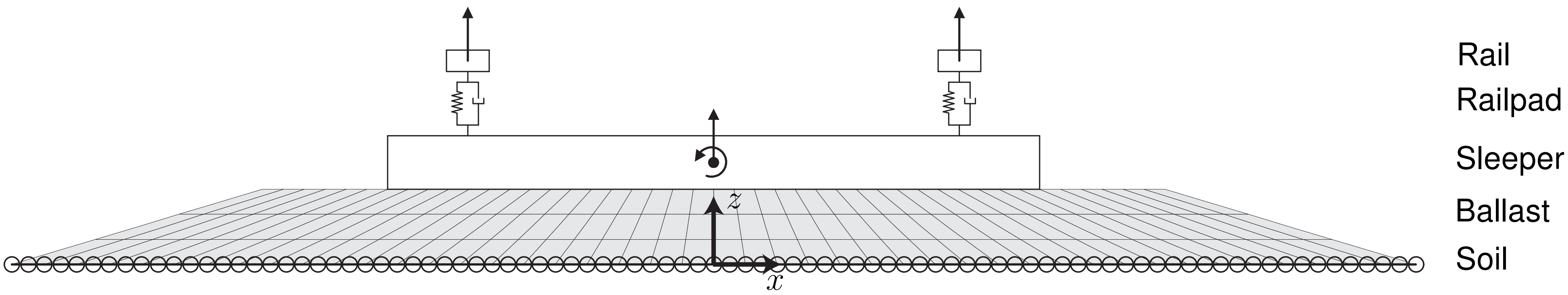
Case study

Site at Lincent (Belgium), along line L2 Brussels - Köln

- Measurements during homologation of L2 (09/2002) for 11 passsages of InterCity train and 11 passages of Thalys High Speed Train (HST).
- Elaborate tests to identify dynamic track and soil characteristics.

Case study

Cross section of model



- The cross section of the track is assumed to be translationally invariant.
  - Rails: Euler-Bernoulli beams.
  - Railpads: Distributed spring-damper connection.
  - Sleeper: Distributed mass, rigid in cross-section plane.
  - Ballast: Elastic continuum.
  - Soil: Layered elastic halfspace.

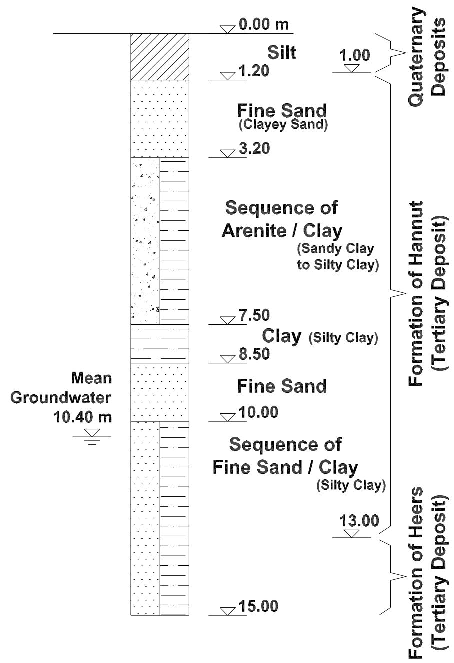
Case study

Track characteristics

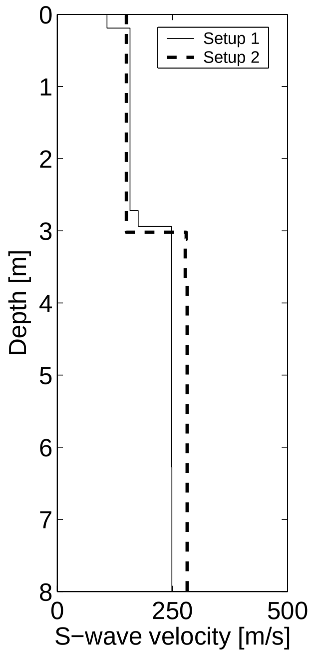
- UIC60 rail.
- Precast prestressed monoblock sleepers (spacing $d = 0.6$ m).
- Pandrol E2039 rail fastening system.
- Pandrol medium stiff resilient rubber railpads type 5197 with a thickness of 11 mm.
- Soft to medium stiff ballast layer (calibre 25/50, $d = 0.35$ m).
- Sub-ballast porphyry layer (calibre 0/32, $d = 0.60$ m).
- Improved soil layer ($d = 1.00$ m).

Case study

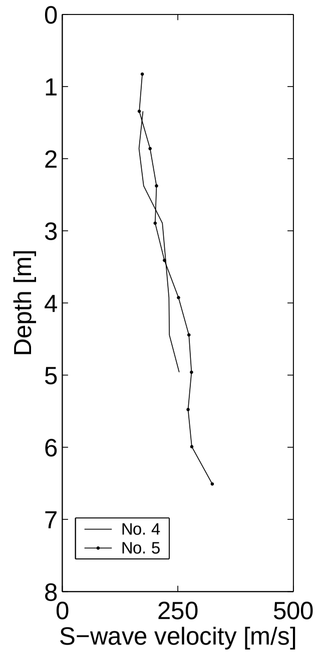
Dynamic soil characteristics



Drilling B1108



SASW



SCPT

- Soft layer ($C_\mathrm{s} = 150\,\mathrm{m/s}$, $C_\mathrm{p} = 300\,\mathrm{m/s}$) with thickness of 3 m on top of stiffer halfspace ($C_\mathrm{s} = 280\,\mathrm{m/s}$, $C_\mathrm{p} = 560\,\mathrm{m/s}$). Density $\rho = 2000\,\mathrm{kg/m^3}$ and material damping ratio $\beta = 0.03$ assumed for both.

Numerical model

Prediction of ground borne vibration

- The response at a point $\mathbf{x}'$ due to a set of n_a moving loads is calculated as follows:

$$u(\mathbf{x}', t) = \sum_{k=1}^{n_\mathrm{a}} \int_{-\infty}^{t} H_\mathrm{ts}(\mathbf{x}_k(\tau), \mathbf{x}', t-\tau) g_k(\tau) d\tau$$

  where $H_\mathrm{ts}(\mathbf{x}, \mathbf{x}', t)$ is a transfer function that relates the load at $\mathbf{x}$ to the response at $\mathbf{x}'$, $\mathbf{x}_k(\tau)$ is the time dependent position of the k-th axle

- The time history of the load $g_k(\tau)$ includes the static and dynamic load component:

$$g_k(\tau) = g_{\mathrm{s}k}(\tau) + g_{\mathrm{d}k}(\tau)$$

Numerical model

Prediction of ground borne vibration

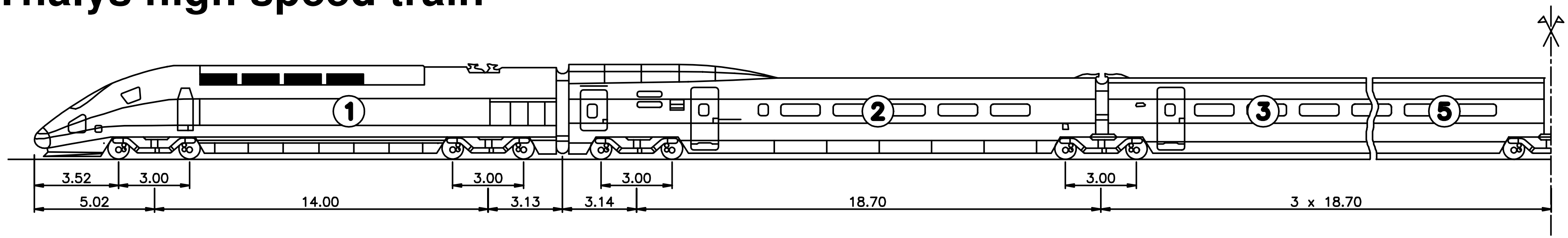
- Dynamic axle loads $\hat{\mathbf{g}}_{\mathrm{d}}(\omega)$ are computed accounting for excitation due to geometric unevenness and disregarding parametric excitation:

$$[\hat{\mathbf{C}}^{\mathrm{t}}(\omega) + \hat{\mathbf{C}}^{\mathrm{v}}(\omega)]\hat{\mathbf{g}}_{\mathrm{d}}(\omega) = \hat{\mathbf{u}}_{\mathrm{w/r}}(\omega)$$

  where $\hat{\mathbf{u}}_{\mathrm{w/r}}(\omega)$ is the wheel/rail unevenness, $\hat{\mathbf{C}}^{\mathrm{t}}(\omega)$ and $\hat{\mathbf{C}}^{\mathrm{v}}(\omega)$ are the track and vehicle compliance, respectively.
- The track compliance $\hat{\mathbf{C}}^{\mathrm{t}}(\omega)$ is computed in a frame of reference that travels with the train.
- The vehicle compliance $\hat{\mathbf{C}}^{\mathrm{v}}(\omega)$ is computed based on a multibody model (simple unsprung mass).

Case study

Thalys high speed train

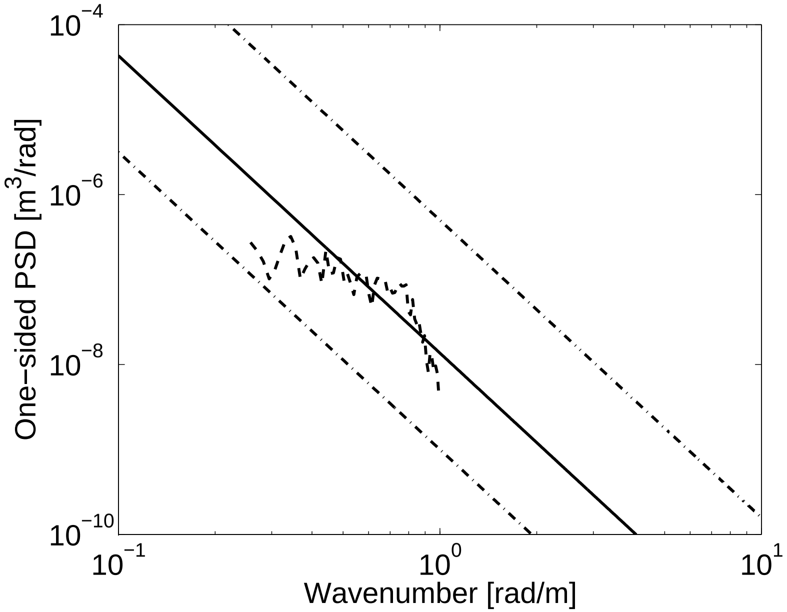


	Axles [-]	L_t [m]	L_b [m]	L_a [m]	M_t [kg]	M_u [kg]
2 Locomotives	4	22.15	14.00	3.00	17000	2027
2 Side coaches	3	21.84	18.70	3.00	17000	2027
3 Central coaches	2	18.70	18.70	3.00	17000	2027

- Total mass M_t carried by each axle defines the static load component, unsprung mass M_u is used to compute the dynamic load component.

Case study

Track unevenness measured by the EM-130 measurement coach

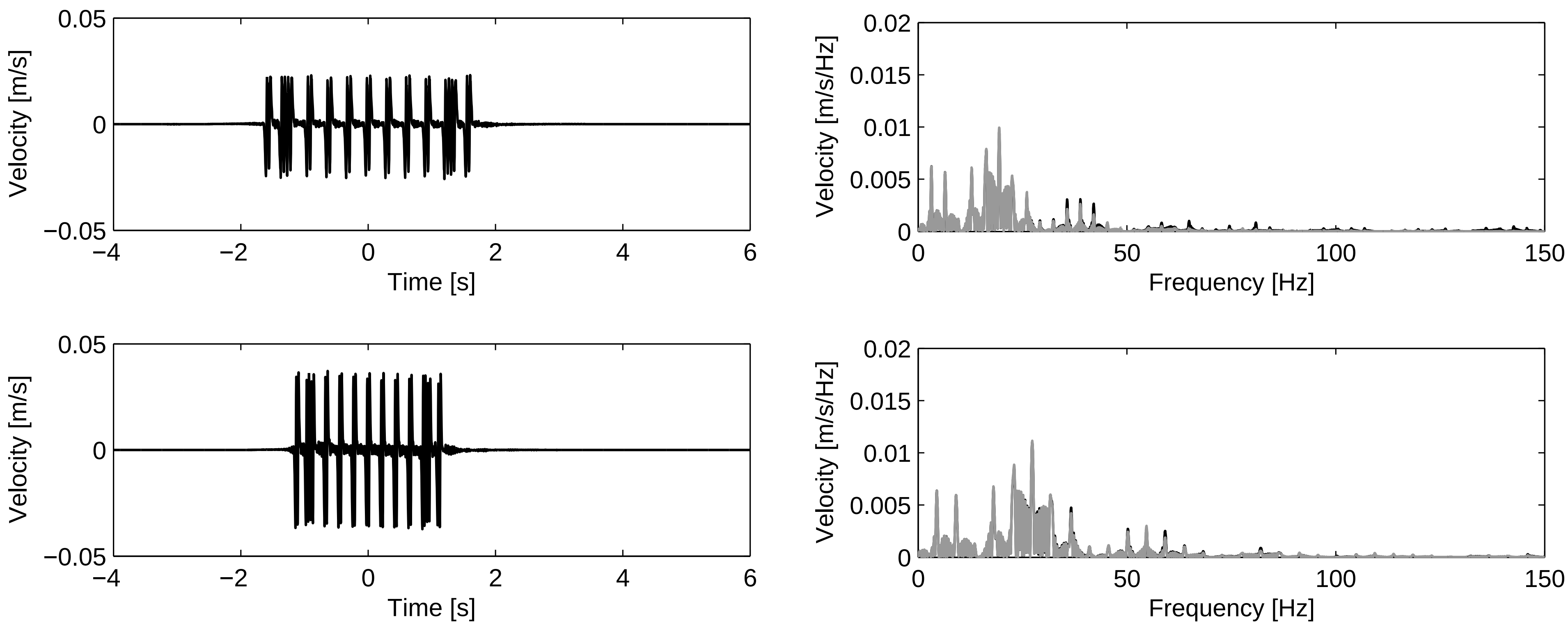


- Track unevenness measured for wavelengths λ between 6 m and 24 m.
- For excitation frequencies $f = v/\lambda$ between 3 Hz and 100 Hz and train speeds v between 100 km/h and 300 km/h, a range of wavelengths between 0.3 m and 30 m is required.

Case study

Predicted sleeper velocity

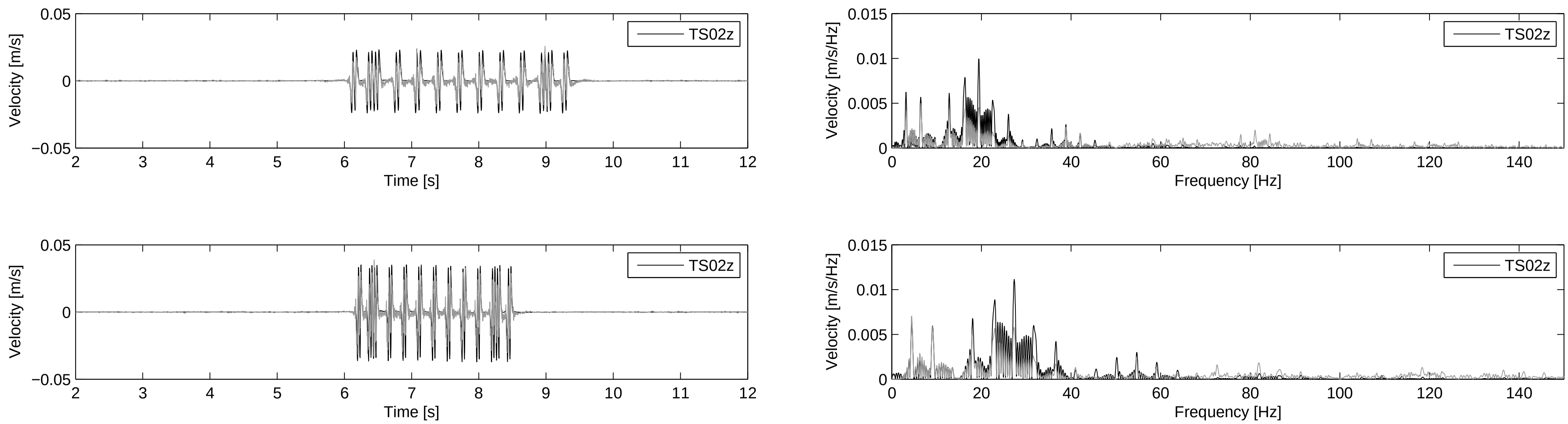
- Time history (left) and narrow band spectrum (right), quasi-static in grey, for a Thalys HST at 218 km/h (top) and 307 km/h (bottom).



Case study

Predicted (black) and measured (grey) sleeper velocity

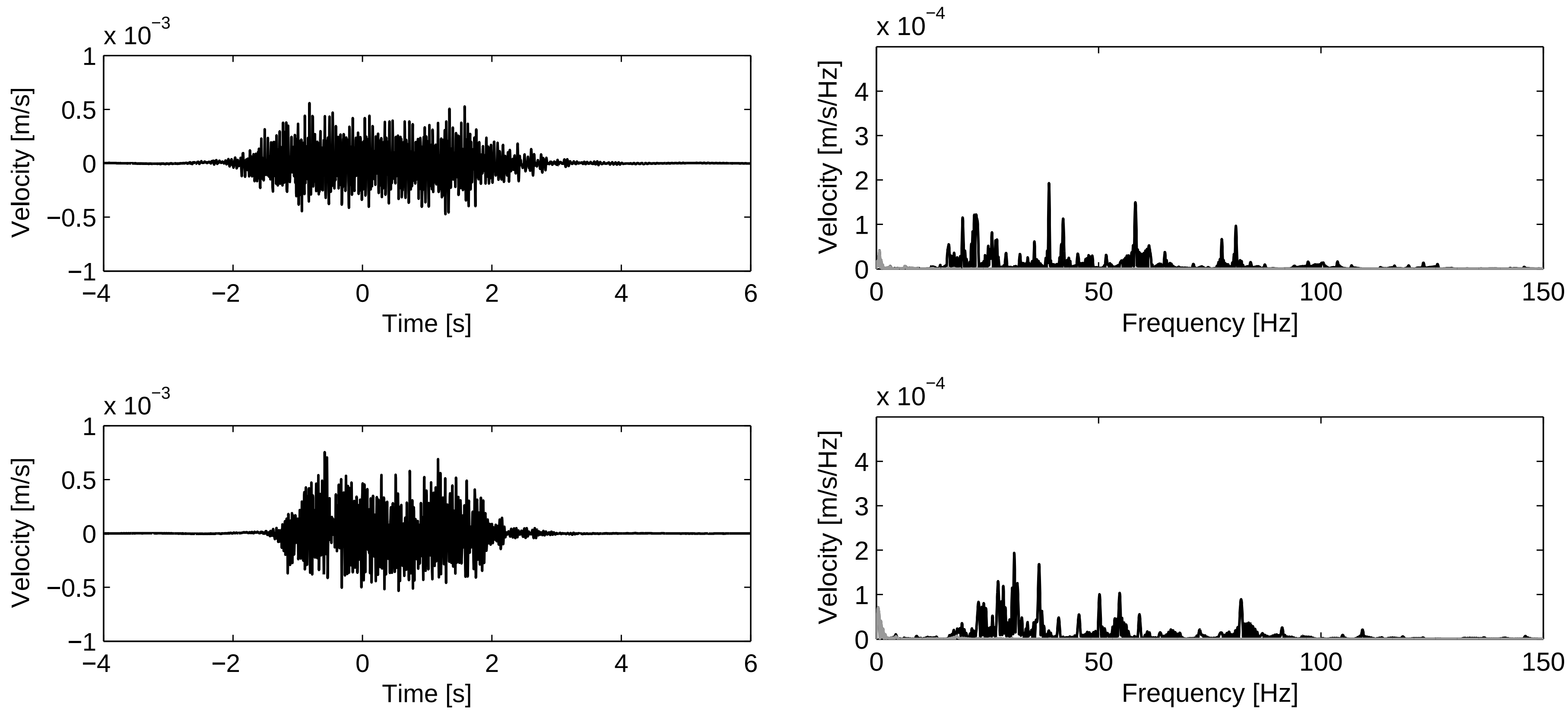
- Time history (left) and narrow band spectrum (right) for a Thalys HST at 218 km/h (top) and 307 km/h (bottom).



Case study

Predicted free field velocity at 16 m from the track

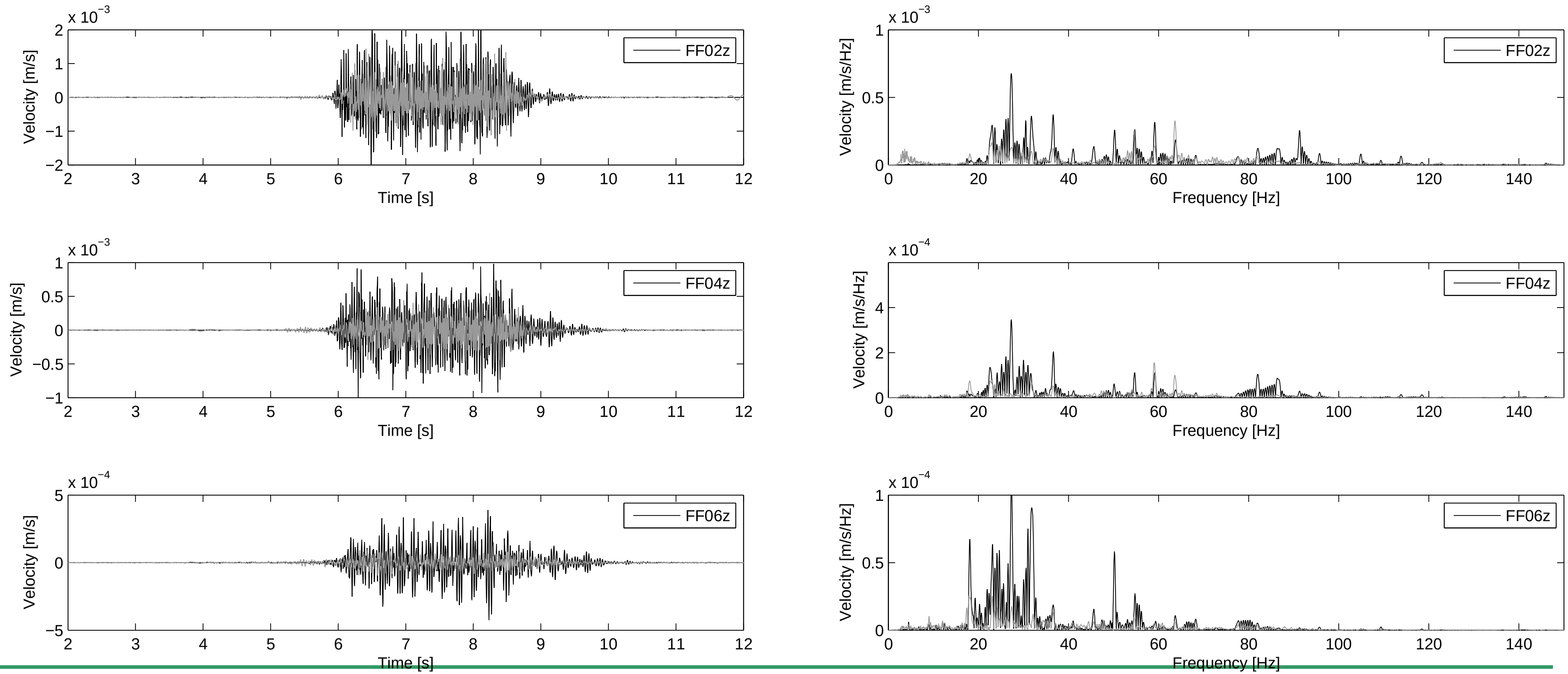
- Time history (left) and narrow band spectrum (right), quasi-static in grey, for a Thalys HST at 218 km/h (top) and 307 km/h (bottom).



Case study

Predicted (black) and measured (grey) free field velocity

- Time history (left) and narrow band spectrum (right) at 8 m (top), 16 m (middle), and 32 m from the track for a Thalys HST at 307 km/h.



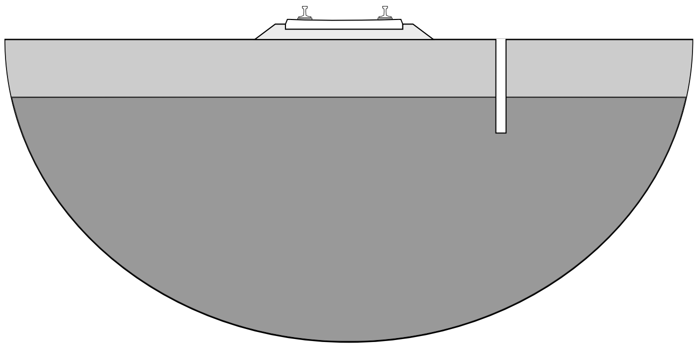
Mitigation measures

Mitigation measures at source

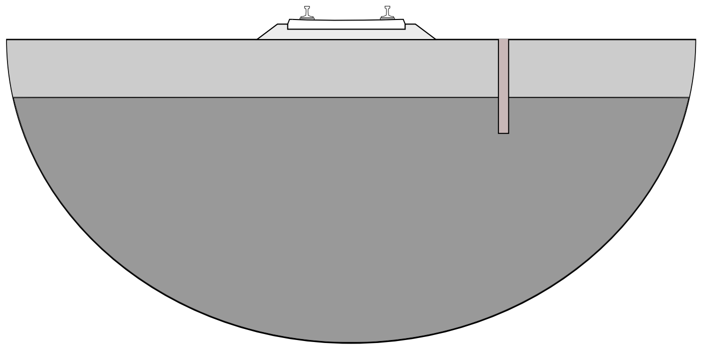
- Examples of mitigation measures at source:
  - Wheel and track: reduction of long wavelength unevenness and parametric excitation.
  - Rolling stock: softer primary suspension, reduction of unsprung mass.
  - Track structure: resilient track elements (under sleeper pads, ballast mats, floating slab tracks).
- Many of these mitigation measures will mainly lead to a reduction of ground borne noise.
- Mitigation of low frequency vibration is far more difficult.

Mitigation measures

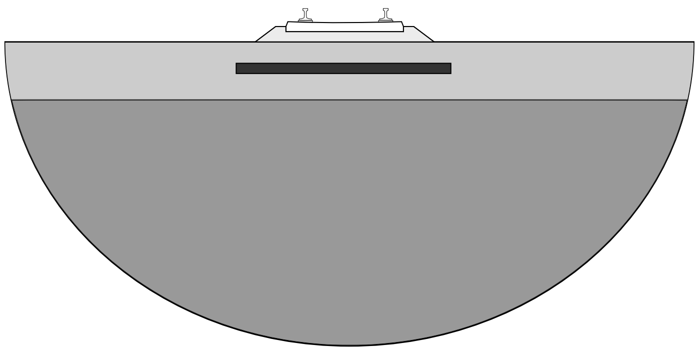
Mitigation measures on the transmission path (studied in RIVAS)



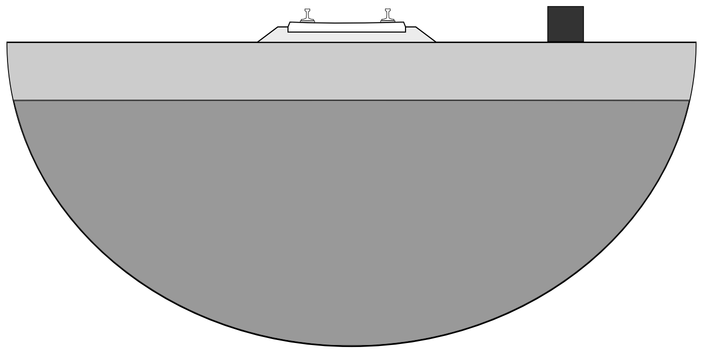
Trenches



Buried wall barriers



Wave impeding blocks



Masses next to track

Mitigation measures

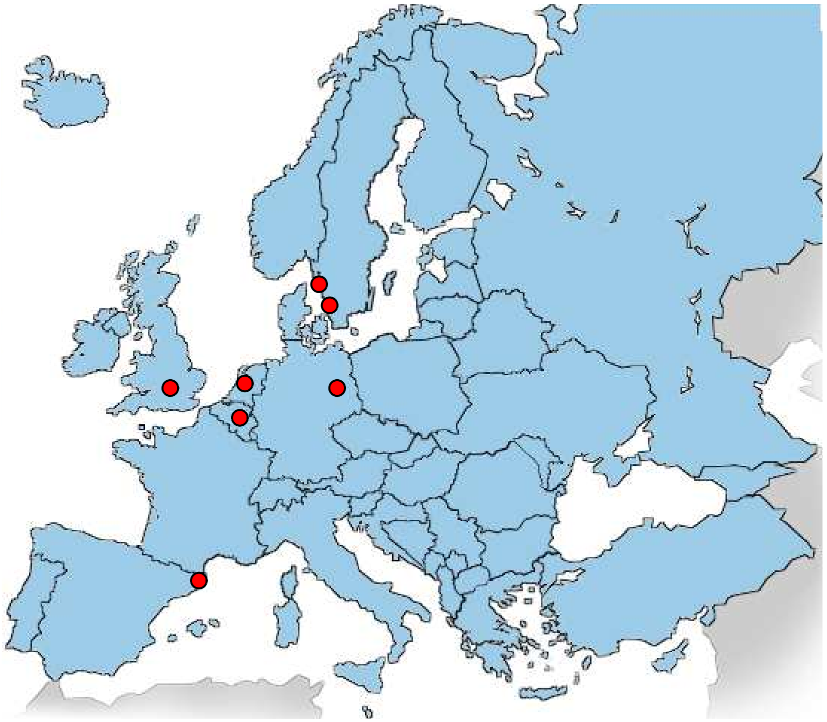
Mitigation measures on the transmission path: approach in RIVAS

- In the frequency range of railway induced vibration, the top layer of soil plays an important role. It leads to a cut-on frequency above which a steep rise in vibration transmission spectrum occurs.
- The key approach is to take the layered structure of the ground into account or to alter its effect to impede wave propagation.
- Relatively modest reductions may be sufficient as perceived railway induced vibration often only slightly exceeds the threshold of perception.

Mitigation measures

Mitigation measures on the transmission path: methodology

- Parametric study for a range of possible designs and ground types, representative of sites with problems of low-frequency vibration.



Mitigation measures

Mitigation measures on the transmission path: methodology

- Mitigation measures studied include trenches, buried wall barriers, subgrade stiffening, wave impeding blocks, and heavy masses next to the track.
- At least two field tests are performed to verify the findings from the numerical simulations:
  - Sheet piling wall on the Trafikverket network in Sweden.
  - Soil stiffening next to the track on the ADIF network in Spain.
  - Trench barrier on the SBB network in Switzerland.
- Partners in RIVAS:
  - ADIF, BAM, CEDEX, DB, ISVR, Keller, KU Leuven, SBB, Trafikverket

Mitigation measures

Mitigation measures on the transmission path

- Session III - Mitigation of vibration by open trenches and soft wave barriers
  - Physical mechanisms
- Session IV - Mitigation of vibration by stiff wave barriers
  - Physical mechanisms
  - Design of field test with jet grouting wall
- Session V - Case study of vibration mitigation by a sheet piling wall
  - Presentation of a test site and mitigation measure
  - Results of numerical simulations and vibration measurements

Conclusions

Conclusions

- Railway induced ground vibration is usually dominated by dynamic excitation, arising from train-track interaction due to wheel and track unevenness, impact excitation, and parametric excitation.
- Mitigation of low frequency vibration, transmitted by surface waves with long wavelengths and large penetration depths, is difficult.
- Within RIVAS, mitigation measures on the transmission path are investigated, fully accounting for the layered nature of soil.
- A large parametric study is performed and at least two field tests will be performed to verify the findings of the numerical simulations.